APPENDIX A

GEOPHYSICAL SURVEY REPORT

APPENDIX A

Geophysical Survey Report
Fill Area West of Range 19
Parcel 233(7)
Fort McClellan, Calhoun County, Alabama

August 2001

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List of Acronyms

EM	electromagnetic
EM31	Geonics Limited EM31 Terrain Conductivity Meter
G-856AX	Geometrics, Inc. G-856AX magnetometer
G-858G	Geometrics, Inc. G-858G magnetic gradiometer
GPS	global positioning system
N-S	north to south
NAD	North American Datum
SFSP	site-specific field sampling plan

A.1.0 Introduction

Shaw Environmental, Inc. (Shaw) conducted a surface geophysical survey at the Fill Area West of Range 19, Parcel 233(7), at Fort McClellan in Calhoun County, Alabama, on January 29, 2000. This survey was conducted for the U.S. Army Corps of Engineers-Mobile District, under Total Environmental Restoration Contract No. DACA21-96-D-0018, Order CK05. The geophysical survey objectives were to determine the presence or absence of subsurface fill materials and, if present, determine the extent of the fill to aid in the selection of the exploratory trench locations. The geophysical survey encompassed approximately 2 acres. The Vicinity Map (Figure A-1) shows the approximate location of the survey area.

Magnetic and frequency-domain electromagnetic (EM) induction methods were implemented for the geophysical investigation. All geophysical data were processed and color enhanced to aid in interpreting subtle anomalies. Following geophysical fieldwork, a survey-grade global positioning system (GPS) and total station were used to document the location of the site.

The survey area had a subtle topography that gently sloped toward the north. The site at the time of the geophysical investigation was primarily forested with a few cleared areas vegetated with grass, as shown on Figure A-2.

Field procedures used during the investigation are described in Chapter A.2.0. The data processing methods used during the investigation are presented in Chapter A.3.0. Data interpretation and criteria used to interpret geophysical anomalies are presented in Chapter A.4.0. Conclusions and recommendations derived from the geophysical surveys are presented in Chapter A.5.0. A description of the equipment and a theoretical discussion of the geophysical methods are presented in the attachment.

A.2.0 Field Procedures

Field procedures are presented in this chapter, including discussions of the survey control and site map, field equipment, data acquisition parameters, and field verification of geophysical anomalies.

A.2.1 Survey Control

The geophysical survey area was identified in the site-specific work plan based on historical site information compiled by Shaw and the environmental baseline survey (Environmental Science and Engineering, 1998). The geophysics crew established a base grid on 100-foot centers throughout the site. Using the base grid as a reference, the crew marked control points on 20-foot centers with surveyor's paint to provide the spatial control required for the investigation. Due to the uncertainty of true field positions inherent when establishing a survey area using 300-foot fiberglass tapes in the presence of wind and surface obstructions (e.g., trees, vehicles, and structures), the lateral precision for the survey areas and anomalies is conservatively estimated to be within plus or minus 1 foot. Following geophysics field work, a GPS survey was conducted at the site referencing the U.S. State Plane Coordinate System (Alabama East Zone, North American Datum [NAD] 1983). The GPS survey was performed in the real-time kinematic mode, which provided nominal sub-centimeter resolution in XY coordinates for the site.

A detailed site map was hand-drawn in the field. The map included any surface features within the survey area or near the perimeter that could potentially affect the geophysical data (e.g., overhead utilities, culverts, etc.). The map also shows reference features, such as buildings, fences, asphalt patches, and survey monuments, that could later aid in reconstructing the site boundaries. All pertinent reference information documented on the hand-drawn site map was placed on the site interpretation map (Figure A-2). Also included on the site map are GPS coordinates to help relocate the survey area.

A.2.2 Geophysical Survey

Field Instruments. The magnetic instruments used during the investigation consisted of a Geometrics, Inc. G-858G magnetic gradiometer (G-858G) for collecting survey data and a Geometrics G-856AX magnetometer (G-856AX) used as a magnetic base station. Frequency-domain EM induction equipment consisted of a Geonics EM31 Terrain Conductivity Meter (EM31) coupled to an Omnidata DL720 digital data logger. A Trimble 4000SSI Total Station GPS and a Sokkia SET5F Total Station Instrument were used to conduct the civil survey work.

All geophysical data were collected using the following Shaw standard operating procedures:

- GP-001 Surface magnetic surveys
- GP-002 Surface frequency-domain electromagnetic surveys
- GP-005 GPS survey
- GP-010 Total station surveys
- GP-012 Geophysical data management.

Field Instrument Base Station. A field instrument base station was established at the site to provide quality control for the geophysical survey data collected. The base station location was chosen to be free of surface and subsurface cultural features that could affect the geophysical data. Standard field procedures were to occupy the base station and collect readings with the survey instruments (magnetic and EM31) before and after each data collection session. These base station files were then reviewed to assess instrument operation. Base station file names and average data values were recorded on base station summary forms.

A.2.2.1 Magnetic Survey

Magnetic Base Station. A magnetic base station was established at Fort McClellan to record diurnal variation in the Earth's magnetic field during the G-858G magnetic gradiometer survey. The magnetic base station was located in a grove of small pine trees on the south side of Castle Avenue (near Parcel 151[7]). This location was determined to be free of surface and subsurface cultural interference (e.g., fences, utilities, and surface/buried metal objects) that could affect the data. The G-856AX magnetometer base station was time-synchronized with the G-858G survey instrument and programmed to record the Earth's background magnetic field at 10-second intervals during the magnetic survey. The background magnetic field data also showed that the survey was conducted during a time of diurnal quiescence.

G-858G Data Collection. Magnetic field measurements were made with the two sensors of the G858-G spaced 2.5 feet (0.76 meters) apart; the lower sensor was 2.0 feet above the ground surface and the upper sensor was 4.5 feet above the ground surface. At the start and end of each data collection session, approximately 60 readings were recorded with the G-858G at the field instrument base station to verify that the instrument was operating properly and to provide a quantitative record of instrument variation during the survey period. A review of these base station files indicates that the instrument was operating properly and the instrument drift was within acceptable limits. Magnetic survey data were collected at 0.5-second intervals (approximately 2.0- to 2.5-foot intervals) along north to south (N-S) oriented survey lines spaced 20 feet apart, for a total of approximately 4,780 linear feet of survey coverage.

The magnetic data were stored in the internal memory of the G-858G, along with corresponding line and station numbers and time of acquisition. Magnetic survey data were screened in the field to assess data quality prior to completing the investigation. All magnetic survey and base station data were downloaded to a personal computer, backed up on IOMEGA®-compatible zip disks, and are retained in project files.

A.2.2.2 Frequency-Domain EM Survey

EM31 Data Collection. Prior to conducting the EM31 survey, the instrument was calibrated and the in-phase component was zeroed at the field instrument base station. The instrument was operated in the vertical dipole mode, measuring the in-phase and out-of-phase components of the EM field. At the start and end of each data collection session approximately 20 readings were recorded at the field instrument base station to verify that the instrument was operating properly and to provide a quantitative record of instrument variation, or drift, during the survey period. A review of these base station files indicates that the instrument was operating properly and instrument drift was within acceptable limits. Survey data were collected at 5-foot intervals along N-S oriented survey lines spaced 20 feet apart, for a total of approximately 4,780 linear feet of survey coverage.

The EM31 data were stored in the digital data logger along with corresponding line and station numbers. EM31 line profiles were reviewed in the field using the DAT31® program to verify data quality prior to completing the survey. All EM31 survey and base station data were downloaded to a personal computer, backed up on IOMEGA-compatible zip disks, and are retained in project files.

A.2.2.3 Anomaly Verification and Sampling Locations

Anomaly Verification. Preliminary color contour maps of the magnetic and EM31 data were generated and field checked to differentiate between anomalies caused by surface and subsurface sources. Geophysical anomalies verified as being caused by surface features were labeled as such on the field data map. Anomalies caused by buried metallic objects were carefully located in the field and marked on the site map.

Sample Locations. After the geophysical data interpretation was complete all anomalies interpreted to represent fill were marked on data maps and provided to the site manager. The site geophysicist and site manager then determined the sample locations that would meet the criteria established in the site-specific field sampling plan (SFSP) sampling rationale and ensure the safety of the drilling/sampling personnel.

A.3.0 Data Processing

Color Contour Maps. Plots of magnetic and EM31 data were generated using the OASIS Montaj® geophysical mapping system from Geosoft, Inc. These maps were color enhanced to aid with interpreting subtle anomalies. Select contour maps from this site are presented as Figures A-3 through A-5.

A series of data processing steps were required to generate the contour maps. Magnetic gradiometer data were downloaded from the G-858G and converted to an ASCII file using the MAGMAP96® program from Geometrics, Inc. EM31 data were downloaded from the data logger and converted to ASCII files using DAT31 and software from Geonics, Inc. The ASCII data files were then reviewed to assess line numbers, station ranges, and overall data quality. Field data file names and corresponding base station data files were recorded on the data file tracking form. Data screening results were then recorded on the base station summary form. Following data quality assessment, geometry corrections to field data files were made, if necessary, using a text editor and recorded on the geophysical data editing form.

Final, corrected magnetic and EM data files containing local geophysical station coordinates (X,Y) and the geophysical measurement (Z) were converted to OASIS Montaj format and imported into the geophysical mapping software. The data were then gridded using bi-directional gridding with an Akima spline. The grid cell size for the magnetic and EM31 data was chosen to be 2.5 and 5.0 feet, respectively. Color contouring was used to enhance data anomalies. The names of files generated and processing parameters used were recorded on data processing forms. Final processed map names are shown in the data processing box found in the lower left corner of each contour map presented. All completed forms of magnetic and EM data collected during the investigation are retained in project files.

A.4.0 Interpretation of Geophysical Data

The method by which the geophysical data were interpreted and the results of that interpretation are presented in this chapter.

Figure A-2 presents the site map with geophysical interpretation. The interpreted color contour map of total magnetic field for the upper sensor is presented as Figure A-3. Interpreted color contour maps of EM31 conductivity and in-phase component data collected along N-S survey lines are presented as Figures A-4 and A-5, respectively. A theoretical background is presented as an attachment to this appendix. The attachment discusses the factors influencing the observed geophysical response for the various methods and equipment used to conduct the Parcel 233 survey.

In addition to the geophysical interpretation the site map (Figure A-2) contains detailed information on reference features (e.g., asphalt and concrete pavement), so that the survey area and the geophysical anomaly locations can be relocated in the future. Anomalies shown on the site interpretation map correspond to those seen in the magnetic and EM data. Surface reference features shown on the site interpretation map were translated from the hand-drawn site map made in the field. The site interpretation map also references the Alabama East State Plane, NAD 1983 Coordinate System.

A.4.1 Data Interpretation Criteria

Color Contour Map Anomalies. Anomalies shown on the magnetic and EM contour maps range from high to low values and from negative to positive, depending on the type of data displayed. The observed anomalies in the contour map of total magnetic field for the upper sensor have values above and below the average magnetic field intensity of 51,300 nanoTeslas for Anniston, Alabama. The typical magnetic data response to near-surface ferrous metallic debris is an asymmetric south high/north low signature. The upper sensor magnetic data are more useful than the lower sensor data for locating large buried objects because the lower sensor is more sensitive to small near-surface objects; hence the upper sensor magnetic data are presented. The characteristic EM31 anomaly over a near-surface metallic conductor consists of a narrow zone having strong negative amplitude centered over the target and a broader lobe of weaker, positive amplitude on either side of the target. As the depth of the target feature increases, the characteristic EM31 response changes to a positive amplitude centered over the target.

Anomalies present on the contour maps of magnetic and EM31 data are first field checked and correlated with known metallic surface objects and other cultural surface features so that anomalies caused by subsurface sources could be determined. Many of the high-amplitude anomalies seen in the contour maps of the magnetic and EM31 data (Figures A-3 through A-5) are caused by cultural features, including metallic debris. Anomalies caused by surface metal are labeled as such on the data contour maps, and the locations of these features are indicated on the geophysical interpretation map. Anomalies interpreted to be caused by buried metal objects, buried construction debris, underground utilities, etc. are labeled on the data contour maps.

A.4.2 Parcel 233 Data Interpretation

One geophysical anomaly caused by subsurface sources is labeled on the contour maps and is discussed in the following text. The geophysical interpretation map (Figure A-2) shows the location of the anomalous high conductivity areas, buried metal objects, and surface metal that were observed in the data. Small anomalies that are interpreted to represent discrete, buried metal objects are not discussed in the text but are labeled on all data maps.

Anomaly A-1. Anomaly A-1 occurs in the EM31 conductivity data (Figure A-4). The anomaly is an area of high conductivity readings, greater than 5 millisiemens per meter above background, that trends northwest-southeast across the northeastern portion of the site. Nearby metallic debris is absent and the exact cause of the elevated conductivity readings is uncertain. Possible sources for the anomaly include: 1) surface disposal or placement of conductive fill materials, 2) a local increase in the volume of fine-grained sands at the surface associated with construction activities, or 3) abandoned road grade that is partially covered with soil materials.

After the geophysical data interpretation was complete, the anomalies interpreted to represent fill were marked on data maps and provided to the site manager. The site geophysicist and site manager then determined the trench locations that would meet the criteria established in the SFSP sampling rationale and that would ensure the safety of the field personnel performing the trenching, drilling, and sampling.

A.5.0 Conclusions and Recommendations

A surface geophysical survey using magnetic and EM methods was conducted on January 29, 2000 at the Fill Area West of Range 19, Parcel 233(7). The survey objectives were to determine the presence or absence of subsurface fill and, if present, determine the extent of the fill to aid in the selection of the exploratory trench locations.

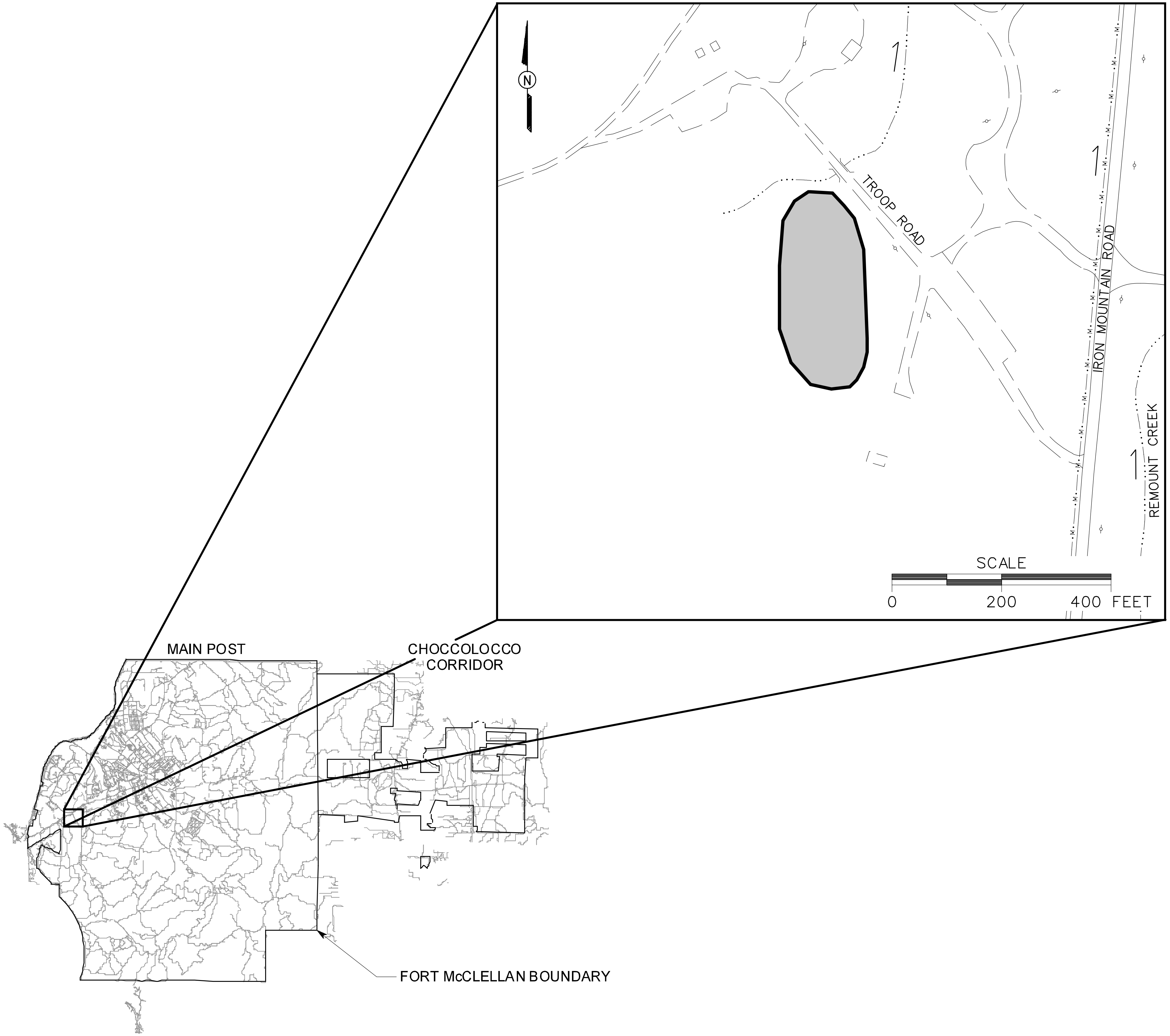
One area of anomalously high conductivity readings was found in the northeastern portion of the site. Nearby metallic debris is absent and the exact cause of the elevated conductivity readings is uncertain. Possible anomaly sources include: 1) surface disposal or placement of conductive fill materials, 2) a local increase in the volume of fine-grained sands at the surface associated with construction activities, and 3) an abandoned road grade that is partially covered with soil materials. The interpretation map also shows the locations of individual surface metal objects and areas of low to moderate concentrations of surface metal.

After the geophysical data interpretation was complete all anomalies interpreted to represent fill were marked on data maps and provided to the site manager. The site geophysicist and the site manager then determined the exploratory trenching locations that would meet the criteria established in sampling rationale and that would ensure the safety of the field crews.

A hand-drawn field map and GPS survey of site features provided a permanent record of the survey boundaries and anomaly locations. Positions shown on the site map generated (Figure A-2) are conservatively estimated to be accurate to within plus or minus 1 foot.

Pipeline locations are indicated on the site interpretation map where evident in the geophysical data. However, the map should not be considered clearance for exploratory trenching or other invasive investigations. Should such clearance be necessary, Shaw recommends proper geophysical clearance using available utility maps, EM utility locator, and ground penetrating radar.

Except for the aforementioned recommendations, no further geophysical investigation is recommended at the Fill Area West of Range 19, Parcel 233(7).



LEGEND

- UNIMPROVED ROADS
- PAVED ROADS
- BUILDING
- FORMER BUILDING
- PARCEL BOUNDARY
- SURFACE DRAINAGE / CREEK W/ FLOW DIRECTION
- MANMADE SURFACE DRAINAGE FEATURE W/ FLOW DIRECTION
- UTILITY POLE

FIGURE A-1
VICINITY MAP
FILL AREA WEST OF RANGE 19
PARCEL 233(7)

U. S. ARMY CORPS OF ENGINEERS
MOBILE DISTRICT
FORT McCLELLAN
CALHOUN COUNTY, ALABAMA
Contract No. DACA21-96-D-0018

Shaw Environmental, Inc.

DWG. NO.: ...\796886es.190
PROJ. NO.: 796886
INITIATOR: J. REMO
PROJ. MGR.: J. YACOUB
DRAFT. CHCK. BY:
ENGR. CHCK. BY: S. MORAN
DATE LAST REV.:
DRAWN BY:
STARTING DATE: 11/25/03
DRAWN BY: D. BOMAR
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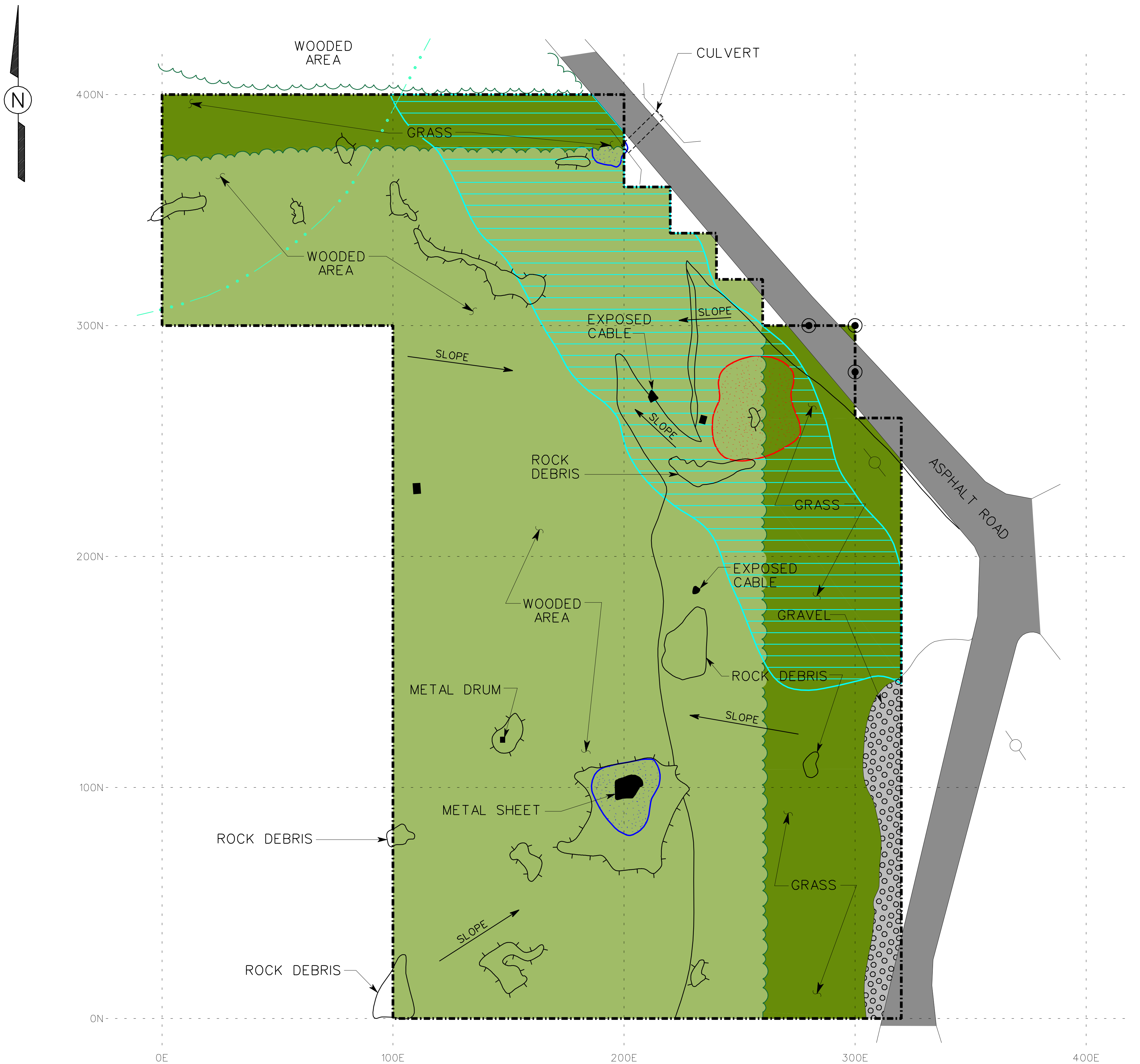

LEGEND

- GEOPHYSICAL SURVEY BOUNDARY
- CIVIL SURVEY STAKE LOCATION
- LOW CONCENTRATION OF BURIED METAL
- HIGH CONDUCTIVITY ANOMALY
- LOW CONCENTRATION OF SURFACE AND/ OR PARTIALLY BURIED METAL DEBRIS
- GRAVEL
- SURFACE METAL OBJECT
- MOUND
- SURFACE DRAINAGE / CREEK
- TREELINE
- UTILITY POLE

NAD 83 SPHEROID, ALABAMA EAST STATE PLANE DATUM		
LOCAL GRID COORDINATES	STATE PLANE COORDINATES	
300N,300E	1165099.562N	664400.345E
300N,280E	1165099.193N	664379.825E
280N,300E	1165079.905N	664400.177E

SCALE
0 50 100 FEET

FIGURE A-2
SITE MAP WITH GEOPHYSICAL INTERPRETATION
FILL AREA WEST OF RANGE 19
PARCEL 233(7)

U. S. ARMY CORPS OF ENGINEERS
MOBILE DISTRICT
FORT McCLELLAN
CALHOUN COUNTY, ALABAMA
Contract No. DACA21-96-D-0018

Shaw Shaw Environmental, Inc.

DWG. NO.: ...\796886es.191
PROJ. NO.: 796886
INITIATOR: C. SCHMALZ
PROJ. MGR.: J. YACOUB
DRAFT. CHCK. BY:
ENGR. CHCK. BY: J. HACKWORTH
DATE LAST REV.:
DRAWN BY:
STARTING DATE: 04/03/01
DRAWN BY: D. BOMAR
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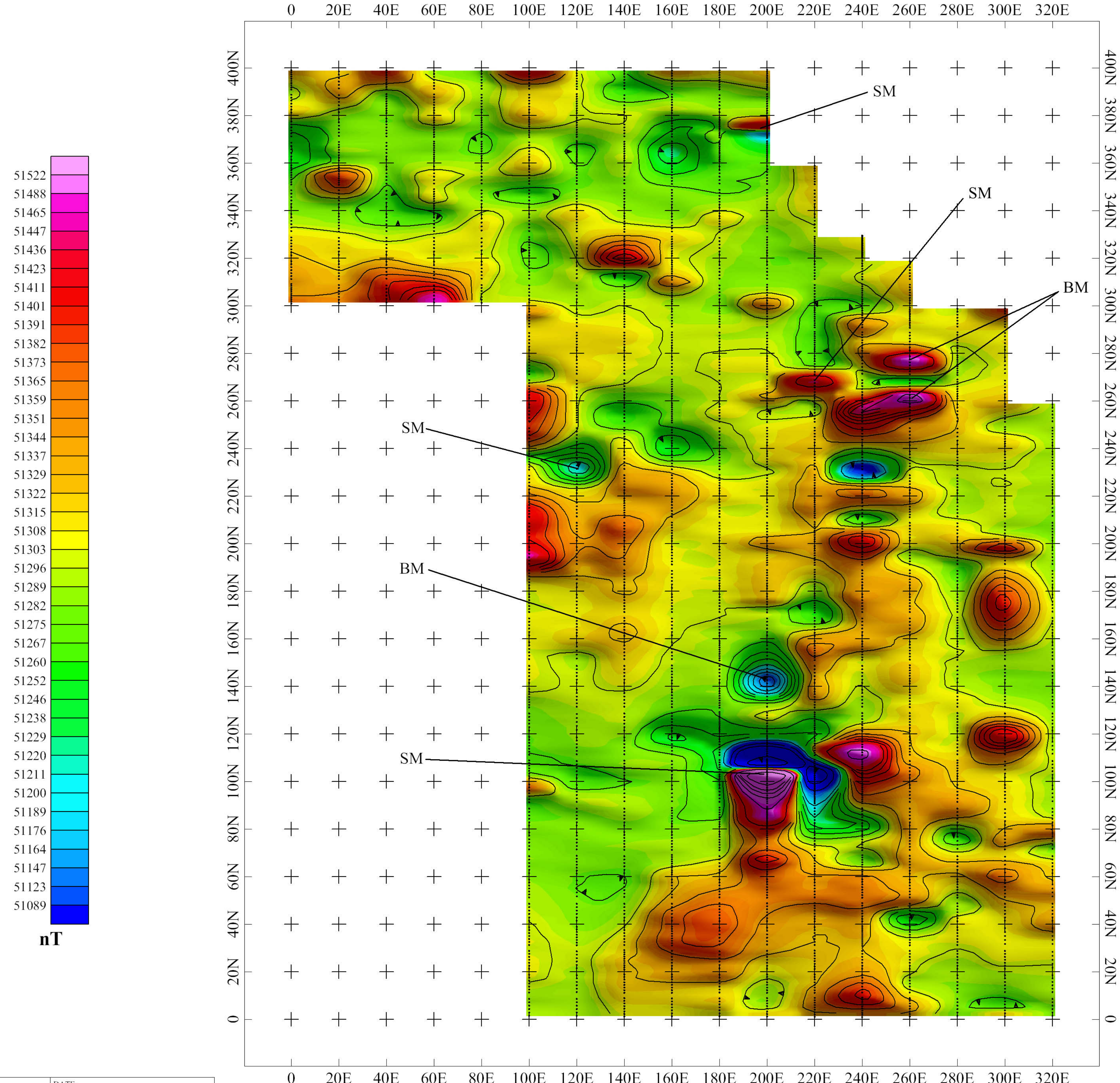


LEGEND:

.... GEOPHYSICAL SURVEY LINES
A-1 GEOPHYSICAL ANOMALY DISCUSSED IN TEXT
BM ANOMALY CAUSED BY BURIED METAL
RC ANOMALY CAUSED BY REINFORCED CONCRETE
SM ANOMALY CAUSED BY SURFACE METAL

Scale 1:600

25 0 25 50 75 100 125
feet

Minimum Contour Interval: 20 nanoTeslas

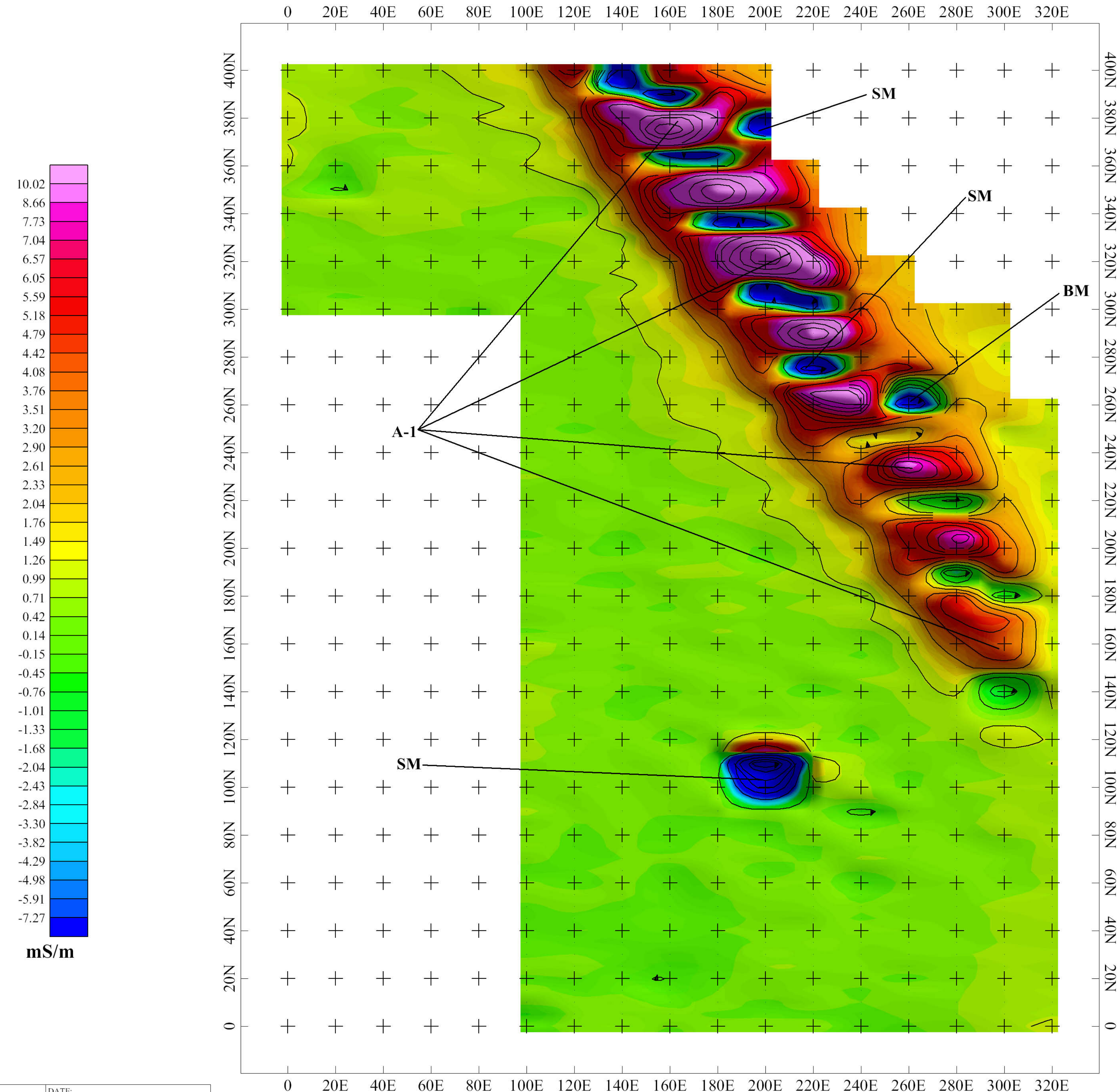
FIGURE A-3
FILL AREA WEST OF RANGE 19
PARCEL 233(7)

G-858G TOTAL MAGNETIC FIELD
UPPER SENSOR (4.5 FT ABOVE GROUND SURFACE)
NORTH-SOUTH SURVEY LINES

U.S. ARMY CORPS OF ENGINEERS
MOBILE DISTRICT
FORT McCLELLAN
CALHOUN COUNTY, ALABAMA
Contract No. DACA21-96-D-0018

Shaw™ Shaw Environmental, Inc.

NAME: Nicholas Muloshi	DATE: February 24, 2000
PROJECT NUMBER: 774645	LOCATION: E:\projects\p233LF3\EM31\p233nc.map



LEGEND:

.... GEOPHYSICAL SURVEY LINES
A-1 GEOPHYSICAL ANOMALY DISCUSSED IN TEXT
BM ANOMALY CAUSED BY BURIED METAL
RC ANOMALY CAUSED BY REINFORCED CONCRETE
SM ANOMALY CAUSED BY SURFACE METAL

Scale 1:600

25 0 25 50 75 100 125
feet

Minimum Contour Interval: 1 milliSiemens per meter

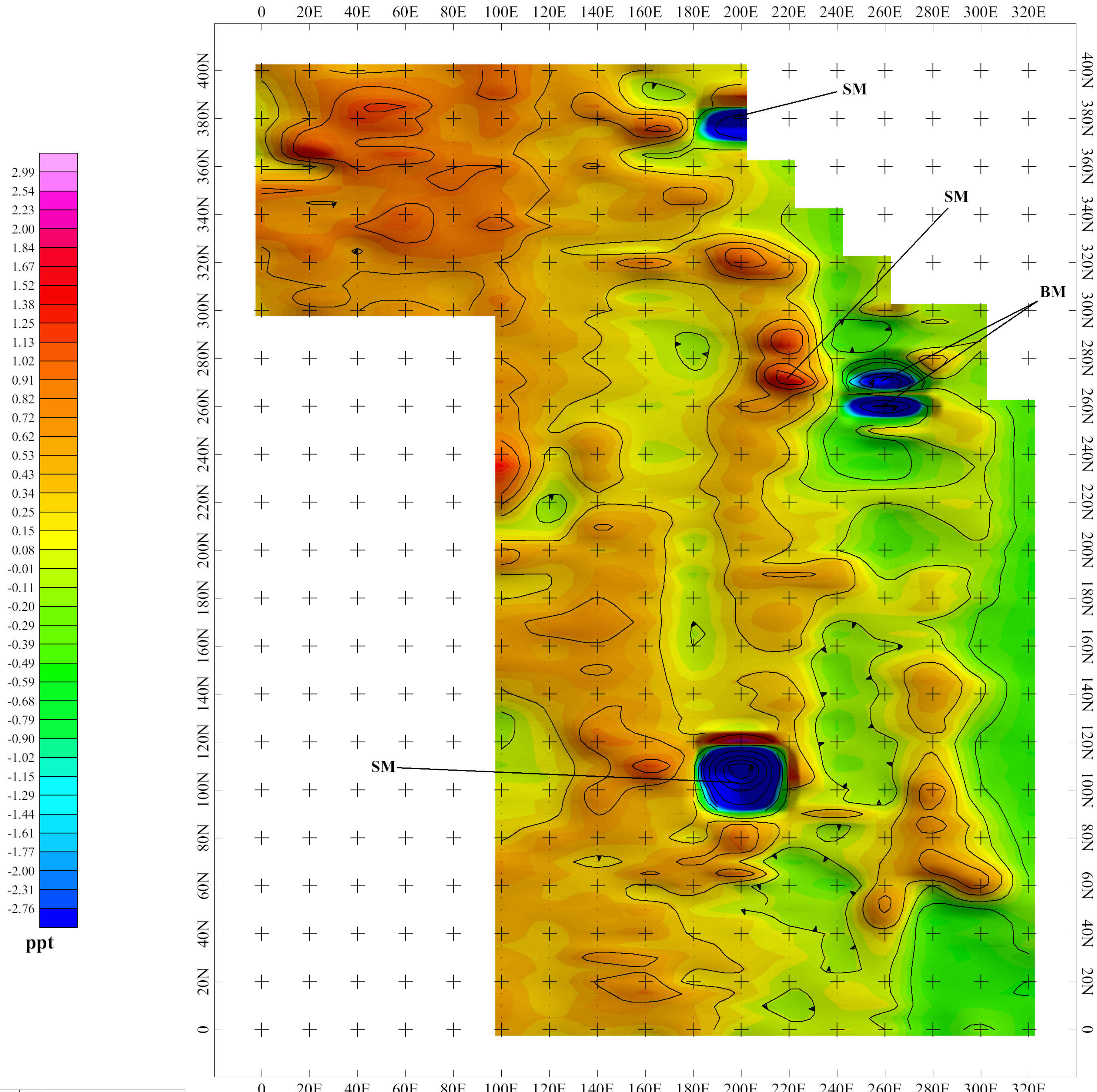
FIGURE A-4
FILL AREA WEST OF RANGE 19
PARCEL 233(7)

EM31 CONDUCTIVITY
VERTICAL DIPOLE (3.0 FT ABOVE GROUND SURFACE)
NORTH-SOUTH SURVEY LINES

U.S. ARMY CORPS OF ENGINEERS
MOBILE DISTRICT
FORT McCLELLAN
CALHOUN COUNTY, ALABAMA
Contract No. DACA21-96-D-0018

Shaw™ Shaw Environmental, Inc.

NAME: Nicholas Muloshi	DATE: February 24, 2000
PROJECT NUMBER: 774645	LOCATION: E:\projects\p233LF3\EM31\p233nc.map



LEGEND:

.... GEOPHYSICAL SURVEY LINES
BM ANOMALY CAUSED BY BURIED METAL
RC ANOMALY CAUSED BY REINFORCED CONCRETE
SM ANOMALY CAUSED BY SURFACE METAL

Scale 1:600

25 0 25 50 75 100 125
feet

Minimum Contour Interval: 0.25 ppt Secondary to Primary Field

FIGURE A-5
FILL AREA WEST OF RANGE 19
PARCEL 233(7)

EM31 IN-PHASE COMPONENT
VERTICAL DIPOLE (3.0 FT ABOVE GROUND SURFACE)
NORTH-SOUTH SURVEY LINES

U.S. ARMY CORPS OF ENGINEERS
MOBILE DISTRICT
FORT McCLELLAN
CALHOUN COUNTY, ALABAMA
Contract No. DACA21-96-D-0018

NAME: Nicholas Muloshi	DATE: February 24, 2000
PROJECT NUMBER: 774645	LOCATION: E:\projects\p233LF3\EM31\p233ni.map

Shaw Environmental, Inc.

ATTACHMENT
THEORETICAL BACKGROUND

Table of Contents

List of Acronyms

EM	electromagnetic induction
EM31	Geonics Limited EM31 terrain conductivity meter
G-856	Geometrics Inc. G-856 magnetometer
G-858G	Geometrics Inc. G-858G magnetic gradiometer
nT	nanoteslas
nT/m	nanoteslas/meter

1.0 Magnetic Method

The magnetic instruments used during the Fort McClellan surface geophysical surveys were a Geometrics, Inc., G-858G "walking mode" magnetic gradiometer (G-858G) for acquiring survey data and a Geometrics, Inc., G-856 magnetometer (G-856) for collecting magnetic base station data.

The G-858G, which is an optically pumped cesium vapor instrument, measures the intensity of the Earth's magnetic field in nanoTeslas (nT) and the vertical gradient of the magnetic field in nanoTeslas per meter (nT/m). The vertical gradient is measured by simultaneously recording the magnetic field with two sensors at different heights. To determine the vertical magnetic gradient, the upper sensor reading is subtracted from the lower sensor reading, and the result is then divided by the distance between the sensors. The distance between sensors for this investigation was 2.5 feet (0.76 meters). The vertical magnetic gradient measurement allows for better definition of shallower anomalies.

During operation of the G-858G a direct current is used to generate a polarized monochromatic light. Absorption of the light occurs within the naturally precessing cesium atoms found in the instrument's two vapor cells or sensors. When absorption is complete, the precessing atoms become a transfer mechanism between light and a transverse radiofrequency (RF) field at a specific frequency of light known as the Larmor frequency. The light intensity is used to monitor the precession and adjusts the RF allowing for the determination of the magnetic field intensity (Sheriff, 1991).

The Earth's magnetic field is believed to originate in currents in the Earth's liquid outer core. The magnetic field varies in intensity from approximately 25,000 nT near the equator, where it is parallel to the Earth's surface, to approximately 70,000 nT near the poles, where it is perpendicular to the Earth's surface. In Alabama, the intensity of the Earth's magnetic field varies from 50,000 to 51,000 nT and has an associated inclination of approximately 54 degrees.

Anomalies in the Earth's magnetic field are caused by induced or remnant magnetism. Remnant magnetism is caused by naturally occurring magnetic materials. Induced magnetic anomalies result from the induction of a secondary magnetic field in a ferromagnetic material (e.g., pipelines, drums, tanks, or well casings) by the Earth's magnetic field. The shape and amplitude of an induced magnetic anomaly over a ferromagnetic object depend on the geometry, size, depth, and magnetic susceptibility of the object and on the magnitude and inclination of the Earth's magnetic field in the study area (Dobrin, 1976; Telford, et al., 1976). Induced magnetic anomalies over buried objects such as drums, pipes, tanks, and buried metallic debris generally exhibit an asymmetrical, south high/north low signature (maximum amplitude on the south side and minimum on the north in the Northern Hemisphere). Magnetic anomalies caused by buried metallic objects generally have dimensions much greater than the dimensions of the objects themselves. As an extreme example, a magnetometer may begin to sense a buried oil well casing at a distance of greater than 50 feet.

The magnetic method is not effective in areas with ferromagnetic material at the surface because the signal from the surface material obscures the signal from any buried objects. Also, the presence of an alternating current electrical power source can render the signal immeasurable because of the high precision required in the measurement of the frequency at which the protons precess (Breiner, 1973). The precession signal may also be sharply degraded in the presence of large magnetic gradients (exceeding approximately 600 nT/m).

The magnetic field measured at any point on the Earth's surface undergoes low-frequency diurnal variation, called magnetic drift, associated with the Earth's rotation. The source of magnetic drift is mainly within the ionosphere, and its magnitude is sometimes large enough to introduce artificial trends in survey data. The G-856 was used to record this drift for removal from the G-858G survey data during processing.

Applications of the magnetic method include delineating old waste sites and mapping unexploded ordnance, drums, tanks, pipes, abandoned wells, and buried metallic debris. The method also is useful in searching for magnetic ore bodies, delineating basement rock, and mapping subsurface geology characterized by volcanic or mafic rocks.

2.0 Frequency-Domain Electromagnetic Induction Method

Frequency-domain electromagnetic induction (EM) equipment used during this investigation consisted of a Geonics EM31 terrain conductivity meter (EM31) coupled to an Omnidata DL720 digital data logger. The EM31 consists of a 12-foot-long plastic boom with a transmitter coil mounted at one end and a receiver coil at the other. An alternating current is applied to the transmitter coil, causing the coil to radiate a primary EM field. As described by Faraday's law of induction, this time-varying magnetic field generates eddy currents in conductive subsurface materials. These eddy currents have an associated secondary magnetic field with a strength and phase shift (relative to the primary field) that are dependent on the conductivity of the medium. The combined effect of the primary and secondary fields is measured by the receiver coil in phase and 90 degrees out of phase (quadrature) with the primary field. Most geologic materials are poor conductors. Current flow through geologic materials takes place primarily in the pore fluids (Keller and Frischknecht, 1966); as such, conductivity is predominantly a function of soil type, porosity, permeability, pore fluid ion content, and degree of saturation. The EM31 is calibrated so that the out-of-phase component is converted to electrical conductivity in units of millisiemens per meter (McNeill, 1980), and the in-phase component is converted to parts per thousand of the secondary field to the primary EM field. The in-phase component is a relative value that is generally set to zero over background materials at each site.

The depth of penetration for EM induction instruments depends on the transmitter/receiver separation and coil orientation (McNeill, 1980). The EM31 has an effective exploration depth of approximately 18 feet when operating in the vertical dipole mode (horizontal coils). In this mode, the maximum instrument response results from materials at a depth of approximately two-fifths the coil spacing (approximately 2 feet below ground surface with the instrument at the normal operating height of approximately 3 feet), provided that no large metallic features such as tanks, drums, pipes, and reinforced concrete are present. Single buried drums typically can be located to depths of approximately 5 feet, whereas clusters of drums can be located to significantly greater depths if background noise is limited or negligible. In the horizontal dipole mode (vertical coils), the EM31 has an effective exploration depth of approximately 9 feet and is most sensitive to materials immediately beneath the ground surface.

The EM31 generally must pass over or very near a buried metallic object to detect it. Both the out-of-phase and in-phase components exhibit a characteristic anomaly over near-surface metallic conductors. This anomaly consists of a narrow zone having strong negative amplitude centered over the target and a broader lobe of weaker, positive amplitude on either side of the target. For long, linear conductors such as pipelines, the characteristic anomaly is as described when the axis of the coil (instrument boom) is at an angle to the conductor. However, when the instrument boom is oriented parallel to the conductor, a positive amplitude anomaly is obtained.

The application of frequency-domain EM techniques includes mapping conductive groundwater contaminant plumes in very shallow aquifers, delineating oil brine pits, landfill boundaries, and pits and trenches containing buried metallic and nonmetallic debris, and locating buried pipes, cables, drums, and tanks.

3.0 References

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